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Ultra Deep X-ray Survey of the Large Magellanic Cloud

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ABSTRACT

Results of the ultra deep survey of the Large Magellanic Cloud (LMC), performed with the *INTEGRAL* observatory, are presented. The large exposure (~ 7 Ms) spent by the observatory in 2003–2012 observing this region allowed us to detect more than twenty sources: ten belonging to the LMC itself (7 HMXBs, 2 PSRs, 1 LMXB), six of extragalactic origin and others owning to other galaxies from the Local Group — the Milky Way and Small Magellanic Cloud. Four new hard X-ray sources were discovered during the survey in addition to IGR J05414-6858 reported by us earlier; two of them were identified with distant AGNs. We report also for the first time the detection of hard X-rays from the Crab-like pulsar PSR J0537-6910 and identification of the hard X-ray source IGR J05305-6559 with the high-mass X-ray binary EXO 053109-6609.

Key words: Surveys – X-ray:general – (galaxies:) Magellanic Clouds

1 INTRODUCTION

All-sky surveys recently carried out in hard (> 15 keV) X-rays by the *INTEGRAL* and *Swift* observatories led to the discovery of several hundreds new sources that enlarged the total number of known hard X-ray objects known on the sky in 2–3 times (e.g., Krivonos et al. 2010a; Bird et al. 2010; Krivonos et al. 2012; Baumgartner et al. 2010; Cusumano et al. 2010). These observatories simultaneously (*INTEGRAL* — since the beginning of 2003, *Swift* — since the end of 2004) working on the orbit are well supplement each other: *Swift* has more uniform coverage of the sky, but *INTEGRAL* has an advantage in observations of the most crowded fields similar to the Galactic center or Galactic plane. During ~ 10 years of the operation *INTEGRAL* observed deeply several such crowded specially selected sky fields — the ones around 3C273, Coma Cluster, M82, Vela, LMC and others.

The LMC field is the one with the mostly deep coverage to the moment. It was observed many times by telescopes aboard *INTEGRAL* in 2003–2004 and 2010–2012 with a total exposure of ~ 7 Ms. The primary goal of these observations was searching for the lines of direct-escape emission from the radioactive decay of ^{44}Ti from the remnant of Supernova 1987A(Grebenev et al. 2012). Such a long exposure spent for this region, allowed us to study for the first time this nearby galaxy with an unprecedent sensitivity in hard X-rays. Note that this exposure was accumulated mainly during 2 last years and the data of observations used in this paper were not included even in the last revisions of the *IBIS/ISGRI* all-sky survey (e.g., Krivonos et al. 2010a; Bird et al. 2010; Krivonos et al. 2012)

In this work we present sky images of the LMC in hard (20–60 keV) and soft (3–20 keV) X-ray energy bands, including detailed maps of several crowded regions of this galaxy, and the catalogue of all detected sources, including several newly discovered ones. Also, we present broadband (3–100 keV) spectra of eight bright X-ray binaries located in this region (for some of them such spectra are published for the first time). The statistical study of the population of high-mass X-ray binaries (HMXB) in the LMC and the active galactic nuclei (AGNs) detected in this direction will be published elsethere (Lutovinov et al. 2012).

2 OBSERVATIONS AND DATA ANALYSIS

In this work we use the data obtained with the *JEM-X* and *IBIS* (*ISGRI* detector) telescopes aboard *INTEGRAL* (Winkler et al. 2003). The *IBIS* telescope has a relatively wide field of view ($\sim 29^\circ \times 29^\circ$ at zero response, $9^\circ \times 9^\circ$ fully coded field) and moderate ($12'$ FWHM) angular resolution, that in combination with the very high sensitivity in the 20–60 keV band makes it to be the best instrument for deep surveys in hard X-rays. The *JEM-X* telescope has smaller field of view (13° in diameter at zero response, no fully coded field) but slightly better angular resolution ($\sim 3.5'$). Due to restricted sensitivity it was used as the secondary instrument for the survey in order to extend it below 20 keV.

The LMC field was observed with *INTEGRAL* in 2003–

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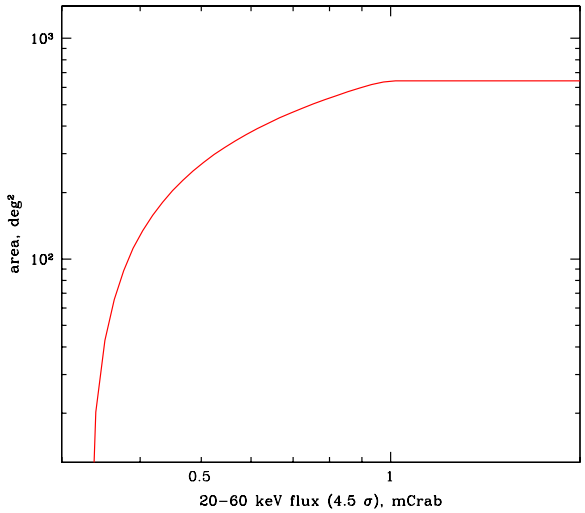

Figure 1. Sky area of the *IBIS/ISGRI* survey as a function of the limiting flux for the 4.5σ-source detection.

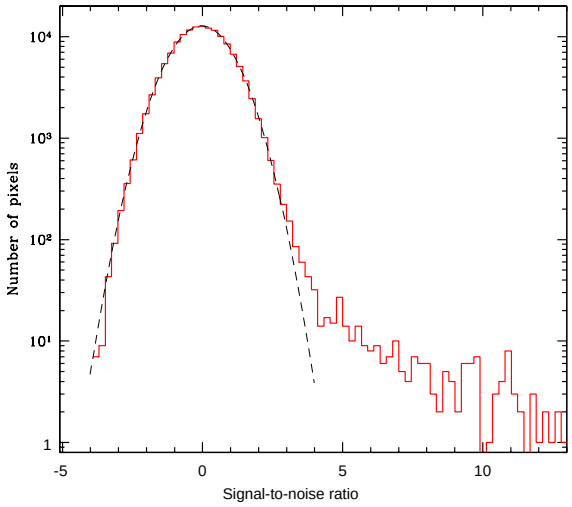

Figure 2. Signal-to-noise ratio distribution of pixels in the 20–60 keV image of the LMC (histogram). The solid line represents the normal distribution with unit variance and zero mean.

2004 (proposals 0120026, 0120146, 0120148, 0120227) and 2010–2012 (proposals 0720017, 0720039, 0820038, 0920022) with a total exposure of ~ 7 Ms (the dead time-corrected exposure of *IBIS/ISGRI* for the central part of the field is $\simeq 4.8$ Ms, for *JEM-X* the effective exposure is smaller $\simeq 1.8$ Ms due to its smaller field of view). The significant part of these observations was carried out in response to our proposals. Reduction of the *IBIS/ISGRI* data was carried out using the methods developed at the Space Research Institute as described by Krivonos et al. (2010b), reduction of the *JEM-X* data — with the standard *OSA* package (version 9.0, see http://isdc.unige.ch). Note that spectra of the detected sources were reconstracted by direct measurement of their flux in the images extracted in the narrow energy bands.

The area of the *IBIS/ISGRI* survey was restricted by the region in which the sensitivity was better than 1 mCrab ($\simeq 1.2\times10^{-11}$ ergs cm^{-2} s^{-1}) at the 4.5σ significance level in the 20–60 keV energy band. The geometrical size of this regions is of about 640 deg^2. The survey area as a function of flux for sources with $S/N > 4.5$ is shown in Fig. 1. It is worth to note, that the central part of the survey (with the area of ~ 240 deg^2), where the LMC is located, has been covered with a sensitivity better than 0.5 mCrab in the 20–60 keV energy band.

One of the main purposes of this survey was searching for previously unknown sources in the LMC field. The detection threshold was estimated assuming Gaussian statistics for pixel values in the accumulated (mosaic) sky image of the LMC. The total area of the image is ~ 640 squared degrees and, taking the *IBIS* angular resolution into account, we gathered $\sim 1.6\times10^4$ independent pixels. With this consideration, the formal detection threshold at the signal-to-noise rato $S/N = 4$ allows at most one false detection. However, the very deep *IBIS/ISGRI* mosaic images may be affected by a systematic noise or some artifacts caused by the imperfect sky reconstruction (Krivonos et al. 2010b). In spite of the absence of strong systematic noise (see Fig. 2) we set a more conservative threshold to be 4.5σ, that diminishes the probability of the false detection more than ten times.

To obtain an accurate localization of newly revealed hard X-ray sources we used data from the follow-up observations performed with the *XRT* telescope aboard the *Swift* observatory (Gehrels et al. 2004).

3 SURVEY

The *IBIS/ISGRI* image of the LMC region in the 20–60 keV X-rays is shown in Fig. 3. The sources detected in the image with the signal-to-noise ratio $S/N \gtrsim 4.5$ are listed in Table 1 (LMC X-3 is included in this table due to its confident detection with the JEM-X telescope). Because of the large field of view of the *IBIS* telescope the size of the sky region covered with the sensitivity better than 1 mCrab is significantly exceeeds that of the LMC itself (~ 640 deg^2 vs ~ 100 deg^2, see Fig. 3, cyan contour). Therefore there are several sources not related to the LMC among those significantly detected in Fig. 3 and listed in Table 1.

Below we discuss all the detected sources and their identifications.

Newly discovered sources

Four new hard X-ray sources with $S/N > 4.5$ were detected in the image. These sources are labeled in Table 1 by a letter [d]. Their coordinates were determined with *IBIS/ISGRI* as follows (epoch J2000, uncertainty of $\sim 4'$):

Name	R.A.	Decl.
IGR J04288-6702	$04^h28^m48^s.2$	-67°02′ 24″
IGR J05048-7340	05 04 46.6	-73 40 01
IGR J05099-6913	05 09 56.6	-69 13 16
IGR J06354-7516	06 35 25.9	-75 16 55

To identify these sources and established their type we made an analysis of available data from X-ray observatories *ROSAT*, *Newton-XMM* and Swift/XRT and scanned different catalogues (*SIMBAD, NED*, etc.). We identified two of the new sources with the known extragalactic objects:

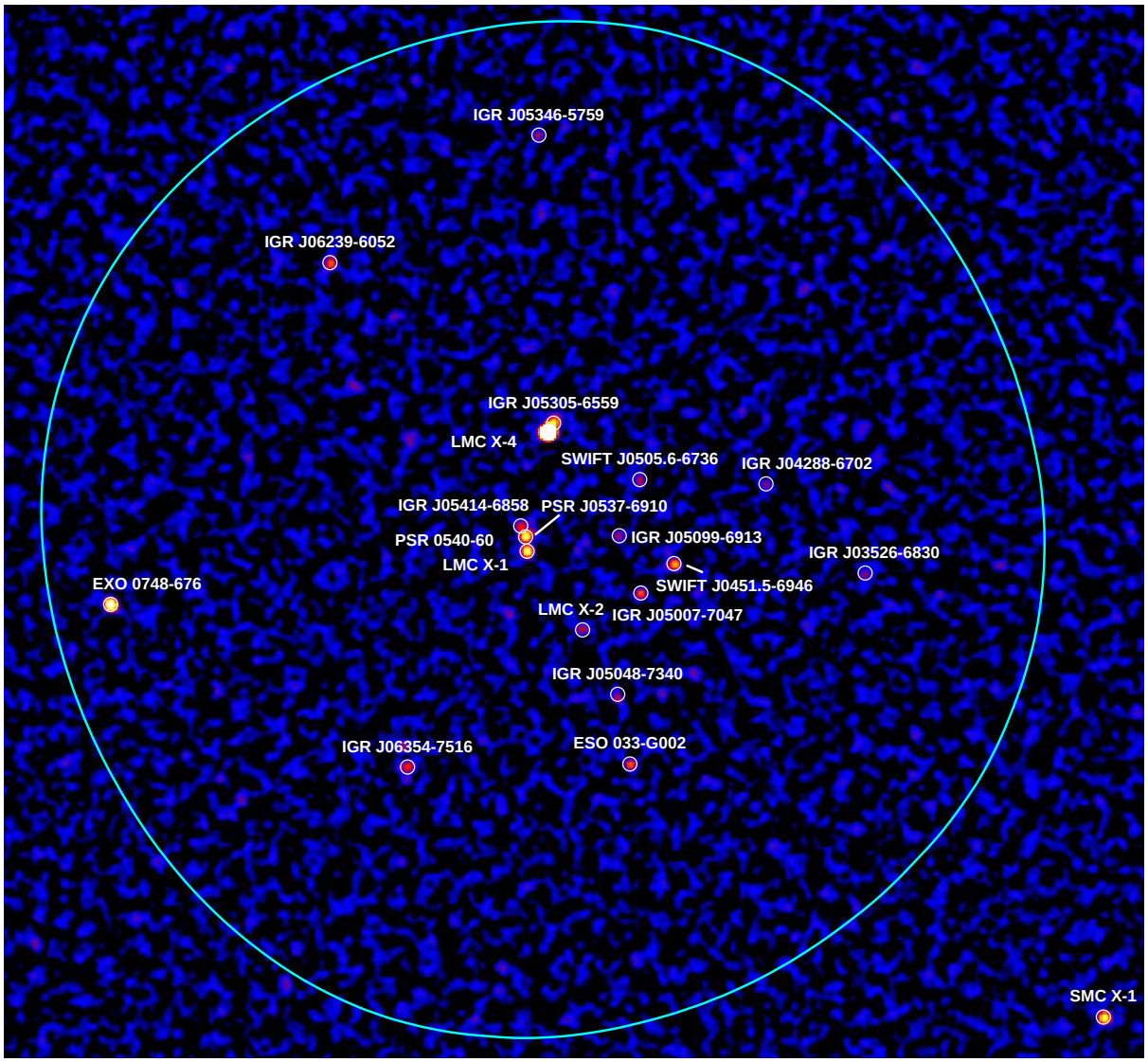

Figure 3. Mosaic image (S/N ratio map) of the LMC field obtained with *IBIS/ISGRI* in the 20–60 keV energy band in 2003-2012. The cyan contour restricts the area with the sensitivity better than 1 mCrab (for detection at 4.5σ). All the sources with $S/N > 4.5$ are labeled.

IGR J06354-7516 — with the quasi-stellar object PKS 0637-752 located at the redshift z=0.653, and IGR J05048-7340 — with the galaxy ESO 033-G011 at the redshift of z=0.0148. We found that the sky region around IGR J05099-6913 was observed many times with the *XRT* telescope of the *Swift* observatory (ObsID. 00030348, 00037825, 00038031, 00090245 for a target "LMC Nova 2005", a total exposure is of $\sim$ 48 ks). No any significant source was detected during these observations inside the *IBIS* error circle of IGR J05099-6913, including the Nova position. The nearest soft X-ray source has coordinates $R.A. = 05^h09^m\ 15\overset{s}{.}6$, $Decl. = -69°08'\,07''$ (J2000, uncertainty $\simeq 4''$) and located $\sim 6'$ away from the *IBIS/ISGRI* position of IGR J05099-6913. It is unlikely, that this object is a soft X-ray counterpart of IGR J05099-6913 because of: 1) formally, the separation of $\sim 6'$ exceeds the uncertainty of the *IBIS/ISGRI* coordinates, 2) the *Swift/XRT* source is very soft (in particular, it is practically undetectable in the 6–10 keV energy band). The sky region near IGR J04288-6702 was observed by *Swift/XRT* with a total exposure of $\sim$ 10 ks in October 2010 (ObsId. 00040907). Two faint soft X-ray sources with coordinates $R.A. = 04^h29^m47\overset{s}{.}2$, $Decl. = -67°03'\,21''$ and $R.A. = 04^h27^m49\overset{s}{.}1$, $Decl. = -67°04'\,36''$ (J2000, uncertainties 4-5$''$) were detected at distances of $\sim 6'$ from the *IBIS/ISGRI* position. Based on these data it is difficult to make any conclusion about a type of IGR J04288-6702; we can mention only that the intensity of the former *XRT* source is $\sim$ 5 times larger than that of the latter source and both of them continue to be visible in the 6–10 keV energy band.

High-mass X-ray binaries

¿From 19 hard X-ray sources listed in Table 1 six ones are high-mass X-ray binaries (HMXBs), located in the LMC. Four of them (LMC X-4, LMC X-1, IGR J05007-7047 and

Table 1. The catalogue of sources detected with $S/N > 4.5$ during the *INTEGRAL* survey of the LMC field[a]

Name	Significance[b]	Flux, mCrab		Type[c], Other names
		$20-60$ keV	$3-20$ keV	
LMC X-4	266.1	21.04 ± 0.08	8.55 ± 0.08	HMXB
EXO 0748-676	39.5	6.88 ± 0.17		LMXB, MW
LMC X-1	25.8	1.98 ± 0.08	9.55 ± 0.07	HMXB, BH
IGR J05305-6559	23.2	1.84 ± 0.08	0.69 ± 0.08	HMXB, EXO 053109-6609
PSR 0540-69	22.0	1.68 ± 0.08	1.28 ± 0.07	PSR
IGR J06239-6052	11.1	1.33 ± 0.12		Sy2, z=0.0405, ESO 121-IG 028
SWIFT J0451.5-6949	14.9	1.22 ± 0.08	0.73 ± 0.09	HMXB
ESO 033-G002	11.7	1.14 ± 0.10	0.60 ± 0.16	Sy2, z=0.0184
IGR J06354-7516[d]	8.7	0.87 ± 0.10		PKS 0637-752, z=0.653, SWIFT J0635.9-7515
IGR J05346-5759	6.2	0.87 ± 0.14		CV, MW
IGR J05007-7047	10.0	0.81 ± 0.08	0.46 ± 0.08	HMXB
IGR J05414-6858	8.0	0.61 ± 0.08		HMXB
IGR J03526-6830	4.8	0.56 ± 0.12		BL Lac, PKS 0352-686, IGR J03532-6829
SWIFT J0505.6-6736	6.4	0.50 ± 0.08		Galaxy, 2MASX J05052442-6734358
LMC X-2	6.1	0.49 ± 0.08	16.90 ± 0.09	LMXB
IGR J04288-6702[d]	5.3	0.49 ± 0.09		
IGR J05099-6913[d]	6.1	0.47 ± 0.08		
IGR J05048-7340[d]	5.3	0.46 ± 0.09		Galaxy, z=0.0148, ESO 033 -G011
PSR J0537-6910	5.8	0.44 ± 0.08	0.25 ± 0.06	PSR
LMC X-3[e]	2.4	0.20 ± 0.08	11.38 ± 0.11	HMXB, BH

[a] sources sorted by their flux in the 20–60 keV band and listed in descending order
[b] in the 20–60 keV energy band
[c] HMXB — high-mass X-ray binary, LMXB — low-mass X-ray binary, CV — cataclysmic variable, PSR — isolated Crab-like pulsar BH — a black hole, MW — the Milky Way galaxy
[d] source discovered in this survey
[e] included due to significant detection in the standard (3–20 keV) X-ray band by the *JEM-X* telescope

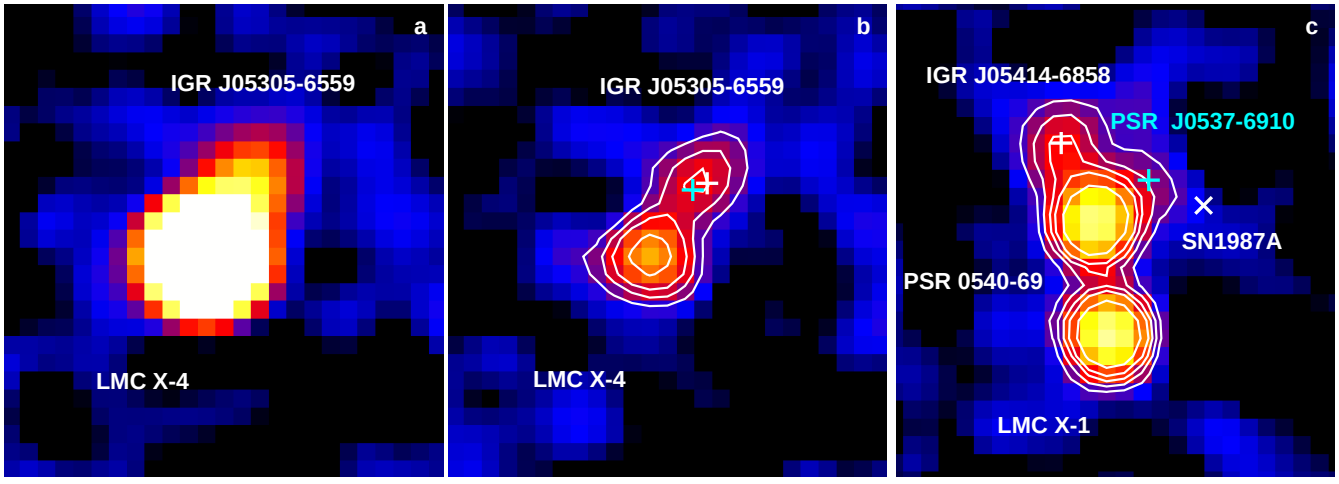

Figure 4. Enlarged *IBIS/ISGRI* maps of two crowded regions in the LMC: near the X-ray pulsar *LMC X-4* (a,b) and near the Crab-like pulsar *PSR 0540-69* (c). The cyan and white crosses in the panel (b) indicate the positions of the soft X-ray sources *EXO 053109-6609* and *XMMU J053041.1-660535*, respectively. Contours correspond to the S/N ratio levels at $3.0, 4.7, 6.4$ and 9.8σ. The cyan cross in the panel (c) indicates a position of the pulsar *PSR J0537-6910*, the white one — a position of *IGR J05414-6858* discovered by us in 2010. The position of the Supernova 1987A remnant is shown by a symbol X. Contours correspond to the S/N ratio levels of $3.0, 4.7, 6.4, 8.1$ and 11.5σ. See text for details.

IGR J05009-7044) were previously reported with an indication of their type (Krivonos et al. 2010a; Bird et al. 2010). The type of SWIFT J0451.5-6949 was established after the discovery of X-ray pulsations with a period of $\simeq 187$ s and its identification with the blue star located in the LMC (Beardmore et al. 2009). The source IGR J05414-6858 was discovered in course of this survey in June 2010 and reported by us earlier (Grebenev & Lutovinov 2010). The follow-up observations with the *Swift/XRT* telescope allowed us to improve the source localization and proposed its optical counterpart (Lutovinov & Grebenev 2010) while the observations with the *Swift/UVOT* and 2.2-m MPG/ESO tele-

Table 2. Fluxes in the 20–60 keV energy band from the known hard X-ray sources in the LMC field not included in Table 1 but still appearing in the *IBIS/ISGRI* mosaic image with $S/N \geq 3\sigma$

Name	Significance[a]	Flux[a], mCrab	Type, Other names
1H 0419-577	3.4	0.76 ± 0.22	Sy1, z=0.104
SWIFT J0450.7-5813	3.8	0.58 ± 0.15	Sy1.5, z=0.0907, RBS 594
ABELL 3266	4.1	0.52 ± 0.13	Galaxies Cluster
SWIFT J0747.9-7327	3.2	0.49 ± 0.15	Galaxy, z=0.0367
SWIFT J0634.7-7445	3.9	0.39 ± 0.10	1RXS J063401.1-744629
IGR J06233-6436	4.0	0.37 ± 0.09	Sy1, z=0.1289, PMN J0623-6436
SWIFT J0609.5-6245	3.0	0.30 ± 0.10	Galaxy

[a] in the 20–60 keV energy band

scopes identified it with a Be-X-ray binary (Rau at al. 2010). Using data of the *XMM-Newton* observations of this source carried out during its outburst in 2011 Sturm et al. (2012) revealed X-ray pulsations with a period of ~ 4.4 s in its light curve and classified it as a X-ray pulsar in high-mass X-ray binary system. The situation with the seventh HMXB is more intriguing. The source IGR J05305-6559 was previously reported by Krivonos et al. (2010a) in the IBIS/ISGRI 7-year all sky survey with the remark "confusion" due to its flux contamination by the nearby bright X-ray pulsar LMC X-4. This made an accurate determination of the IGR J05305-6559 position and its identification to be complex (e.g., Fig. 4a). Fortunately, the X-ray pulsar LMC X-4 demonstrates a superorbital variability with a period of ~ 30.5 days and rahter a long interval of switching-off (the "off"-state). We accumulayed a mosaic image of this region using only the IBIS/SIGRI data related to this "off"-state that allowed us to separate IGR J05305-6559 from LMC X-4 (Fig.4b). It is obviously from the figure that the position of IGR J05305-6559 is consistent with the positions of two soft X-ray sources — EXO 053109-6609 (shown by a cyan cross) and XMMU J053041.1-660535 (a white cross). Taking into account that the luminosity of EXO 053109-6609 in the 2–10 keV band is ~ 20 times higher than the luminosity of XMMU J053041.1-660535 (Shtykovskiy & Gilfanov 2005) we concluded that precisely EXO 053109-6609 is the soft X-ray counterpart of IGR J05305-6559 which is thus a high-mass X-ray binary.

Extragalactic objects

The next large group of sources detected by *IBIS/ISGRI* includes active galactic nuclei and other extragalactic sources. In total six such objects were significantly detected in this survey. Two of them are new ones discovered in this survey and mentioned above. Another two sources are active galactic nuclei of a Seyfert 2 type located at the redshifts $z \simeq 0.018$ and $\simeq 0.04$ (see Table 1). And the latter two are a blazar and a galaxy. It is worse to note that the total number of extragalactic objects detected in the direction to the LMC is smaller than in them most of other directions that can be an indicator of the global non-uniformity of the matter distribution in the local Universe(see Lutovinov et al. 2012, for details).

Other types of detected sources

Although HMXBs is the main population of X-ray sources in the LMC (see, e.g., Gilfanov 2004), *INTEGRAL* has detected one low-mass X-ray binary (LMC X-2) and two rotating powered Crab-like pulsars — PSR 0540-69 and PSR J0537-6910. The former pulsar is the well known source previously detected by any X-ray mission observing the field and included in the catalogues of the *INTEGRAL* and *Swift* all sky surveys. The detailed study of the region around this source showed that the contours of its S/N ratio have not a nearly circular shape as usual, but demonstrate oblongness in two different directions (Fig. 4c). In the one direction the oblongness is associated with the HMXB IGR J05414-6858 discovered by us in 2010 (see above). In the second directon the oblongness coincides with the position of another Crab-like pulsar PSR J0537-6910. The ratio of the fluxes measured by *IBIS/ISGRI* from these pulsars (~ 4) coincides with the ratio of their fluxes measured by *XMM-Newton* in the softer X-ray band (Shtykovskiy & Gilfanov 2005). This is a result of the power law spectra of these pulsars with similar photon indexes. And this confirms our conclusion that precisely PSR J0537-6910 is responsible for the detected oblongness of the S/N ratio contours. This source was detected in hard X-rays for the first time.

Finally, two X-ray sources owned to our Galaxy — - EXO 0748-676 (LMXB) and IGR J05346-5759 (CV) and one source owned to the Small Magelanic Cloud (SMC X-1/HMXB) with the flux of 28.1 ± 1.3 mCrab, located outside the 1 mCrab region, were significantly detected with *IBIS/SIGRI* in the survey.

Fig. 5 shows the LMC image obtained with the *JEM-X* telescope aboard *INTEGRAL* in the 3–20 keV energy band. Due to the smaller field of view of *JEM-X* this image covers only the central part of the hard X-ray survey which corresponds roughly to the LMC galaxy itself. Eight sources from the *IBIS/ISGRI* catalogue were significantly detected in the soft X-rays (see Table 1) and in addition — the very bright black-hole binary LMC X-3 not detected by *IBIS*. The Crab-like pulsar PSR J0537-6910 was marginally detected and its flux can be considered as an upper limit.

Besides of the discussed above sources confidently ($S/N > 4.5$) detected with *IBIS/SIGRI*, several other sources were observed in previous X-ray surveys within the considered region of the *IBIS/SIGRI* 1-mCrab sensitivity. For completeness of this survey, for the sources detected with the $S/N > 3.0$ we estimated fluxes at their positions

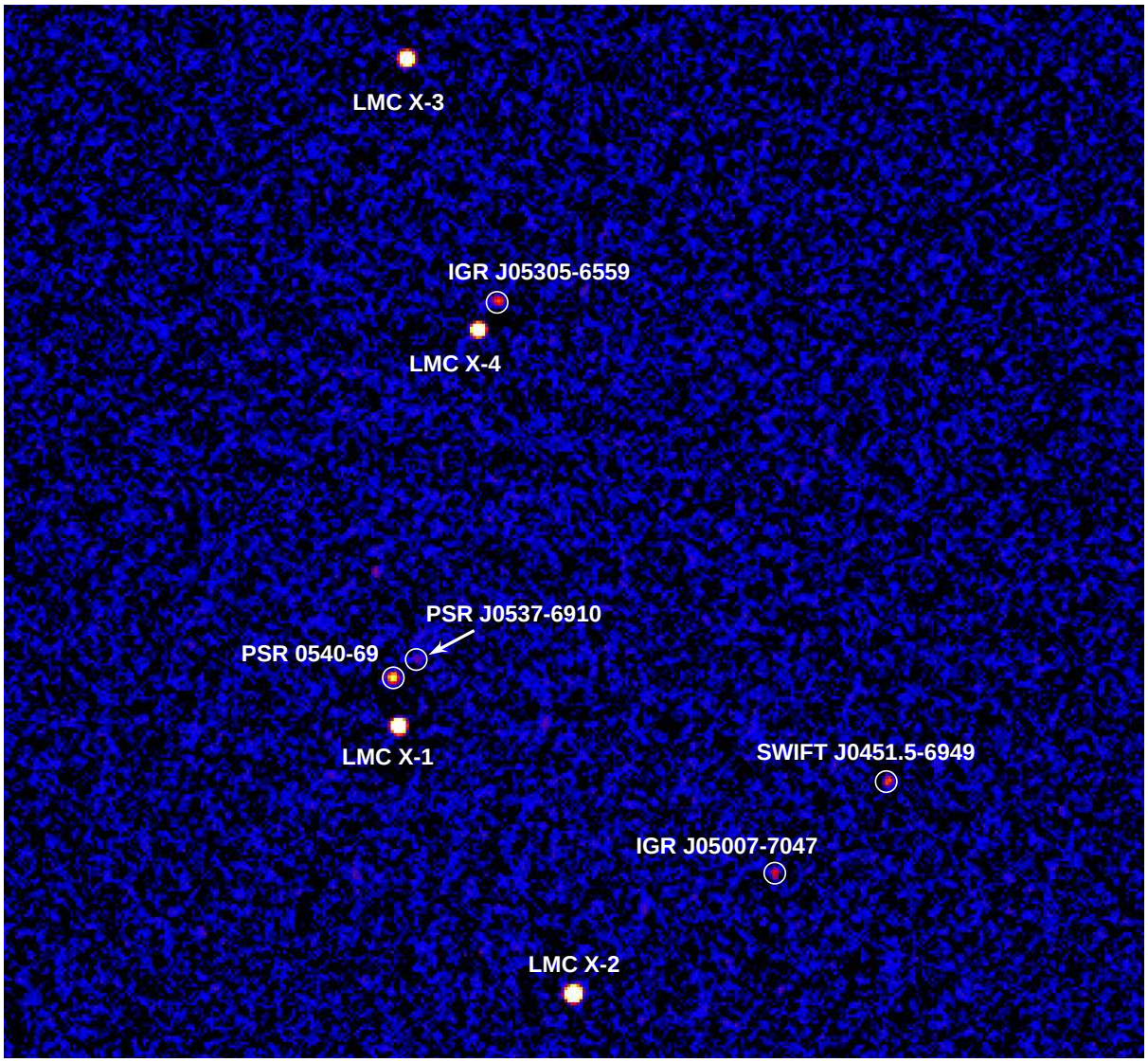

Figure 5. Mosaic image (S/N ratio map) of the LMC field obtained by the *INTEGRAL/JEM-X* telescope in the 3–20 keV energy band. All significantly detected sources are labeled.

in the 20–60 keV band and are listing them in Table 2. In total, the fluxes from seven such sources are presented. Six of them are extragalactic objects, the origin of yet another source is still unclear.

4 BROAD-BAND X-RAY SPECTRA

The broad-band spectra in the 3–200 keV energy band of 8 X-ray sources located in the LMC are presented in Fig. 6. Results of *JEM-X* and *IBIS* measurements are shown by filled circles and crosses, respectively; corresponding approximations with the best-fit models are shown by solid lines. The model parameters are given in Table 3.

It follows from Table 1 that two high-mass X-ray binaries harboring black holes were detected in the survey. The spectrum of LMC X-1 can be successfully described by a two-component model consisting of a disk black-body and a power law (their contribution are shown in Fig. 6 by dash-dotted lines and dashed lines, respectively). Such a model as well as its parameters in Table 3 are typical for objects of this type (Tanaka & Shibazaki 1996; Remillard & McClintock 2006) Another HMXB/BH system, LMC X-3, was significantly detected only by the *JEM-X* telescope (see Table 1). This is connected with the ultrasoft state of this source, whose spectrum can be approximated by a one-component disk black-body model (Fig. 6). The spectrum of LMC X-2 which is a low-mass X-ray binary is also typical for objects of this type. We approximated it with two components: a disk black-body one with the temperature $kT_{in} \simeq 2$ keV describing an emission of the accretion disk, and a bremsstrahlung of an optically thin plasma with the temperature $kT_{br} \simeq 10$ keV describing a hard comptonized X-ray emission of the boundary layer (Grebenev & Sunyaev 2002; Gilfanov 2004; Suleimanov &Poutanen 2006). The pulsar PSR 0540-69 has a power law spectrum with the photon index $\Gamma \simeq 1.7$. The remaining four sources are high-mass X-ray binaries with neutron stars. The spectra of three of them (LMC X-

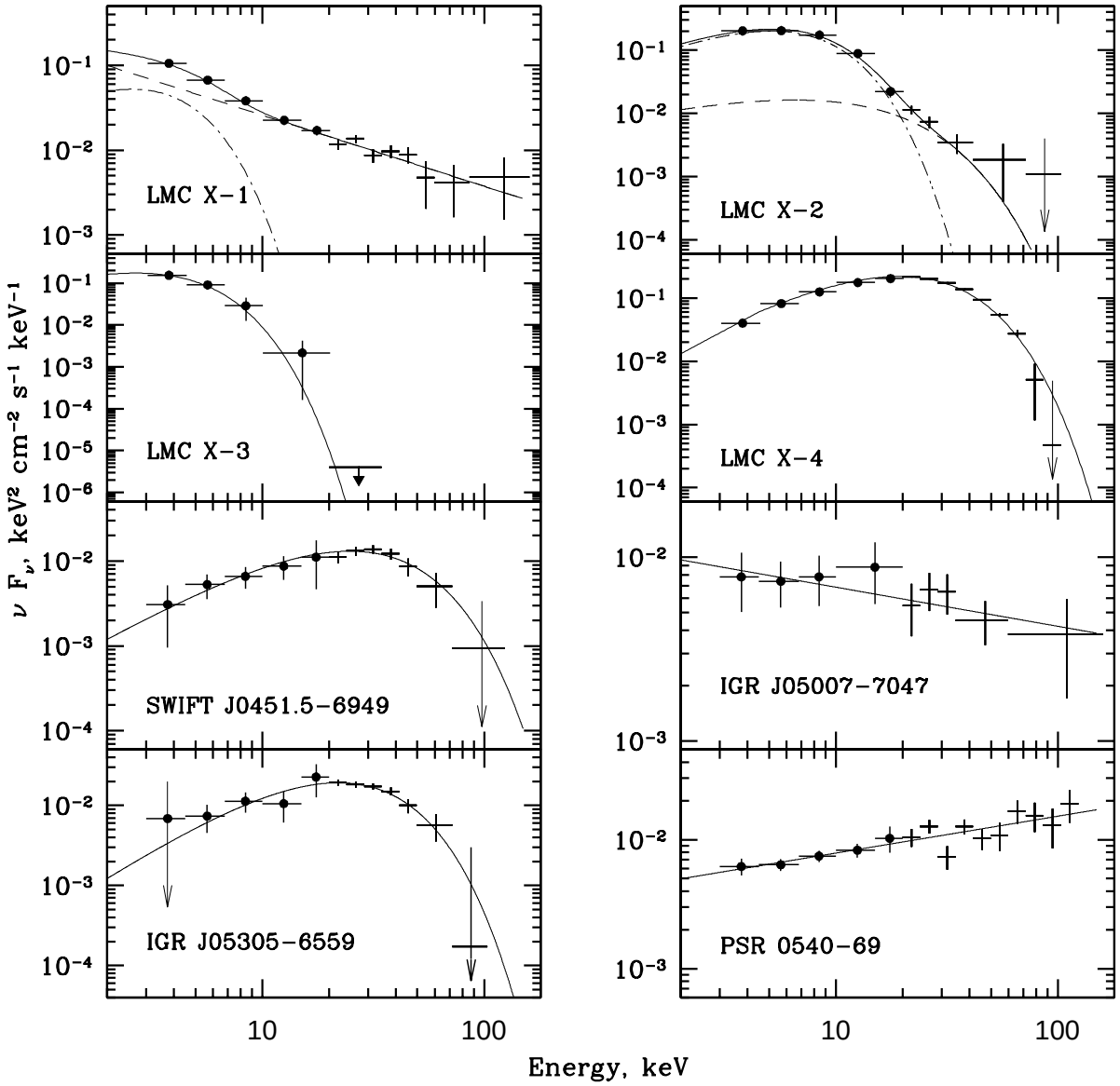

Figure 6. Energy spectra of 8 X-ray sources confidently detected in the LMC with the *INTEGRAL* observatory. Filled circles show results of the *JEM-X* measurements, crosses — the *IBIS/ISGRI* ones. The best-fit models are shown by solid lines. Dashed and dashed-dotted lines represent different components of complex spectral models (see text for details). The bold arrow shows a 3-σ upper limit.

4, SWIFT J0451.5-6949, IGR J05305-6559) are very similar each other and can be approximated by a power law with a high energy cut-off. The fourth source, IGR J05007-7047, is fainter, therefore its spectrum was obtained with large uncertainties in most of energy channels (Fig. 6). It doesn't require complex spectral modeling and can be described by a simple power law. No cyclotron absorption lines were detected in the spectrum of the known X-ray pulsar LMC X-4 that is consistent with the previous reports (Tsygankov & Lutovinov 2005).

Note finally that the broad-band spectra of three sources, SWIFT J0451.5-6949, IGR J05007-7047 and IGR J05305-6559, are obtained (and presented here) for the first time.

5 SUMMARY

We present results of the ultra deep survey of the Large Magellanic Cloud carried out with the *INTEGRAL* observatory in 2003–2012 with an exposure of ~ 7 Ms. The main results can be summarized as follows:

- During this survey 20 X-ray sources were detected by *IBIS/SIGRI* in the 20–60 keV band at the significance level $S/N > 4.5$ (one more source was significantly detected by only the *JEM-X* telescope in the 3–20 keV band). In total *JEM-X* detected 10 sources.
- Ten of these sources belong to the LMC (7 HMXBs, 2 PSRs, 1 LMXB), six sources have extragalactic origin, two belongs to our Galaxy, and one more — to the Small Magellanic Cloud. Two sources is still unidentified.
- Four new hard X-ray sources were discovered in this

Table 3. Best-fit spectral approximation in the 3–100 keV band for 8 X-ray sources shown in Fig. 6

Name	kT_{in}^{a} keV	kT_{br}^{b} keV	Γ^{c}	E_{c}^{d} keV
LMC X-1	1.08 ± 0.06		2.8 ± 0.2	
LMC X-2	2.17 ± 0.03	10 ± 1		
LMC X-3	1.14 ± 0.04			
LMC X-4			0.10 ± 0.05	10.4 ± 0.6
SWIFT J0451.5-6949			0.5 ± 0.5	16.0 ± 5.0
IGR J05007-7047			2.2 ± 0.3	
IGR J05305-6559			0.15 ± 0.65	12 ± 4
PSR 0540-69			1.7 ± 0.1	

[a] inner temperature in the disc black-body model
[b] bremsstrahlung temperature
[c] photon index of the power-law approximation
[d] energy of the high energy cut-off in the spectrum

survey: two of them are extragalactic objects, the type of other two sources is still needed to be established. One more source discovered during this survey has been reported earlier in 2010.

• We report for the first time the detection in hard X-rays the Crab-like pulsar PSR J0537-6910.

• We identified the source IGR J05305-6559 detected by *INTEGRAL* in the close vicinity of the very bright pulsar LMC X-4 with the the soft X-ray source EXO 053109-6609.

• Broadband spectra (3–100 keV) of 8 bright sources are presented and analyzed. For three of these sources such spectra are reproduced and published for the first time.

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